

FINAL REPORT

Optical Amplifier Based Space Solar Power

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Objective: The objective was to design a safe optical power beaming system for use in space. Research was focused on identification of strategies and structures that would enable achievement near diffraction limited optical beam quality, highly efficient electrical to optical conversion, and high average power in combination in a single system. Efforts centered on producing high efficiency, low mass of the overall system, low operating temperature, precision pointing and tracking capability, compatibility with useful satellite orbits, component and system reliability, and long component and system life in space. A system based on increasing the power handled by each individual module to an optimum and the number of modules in the complete structure was planned. We were concerned with identifying the most economical and rapid path to commercially viable safe space solar power.

1. Introduction

For the power beaming system to perform effectively a more powerful laser was needed. An obstacle in creating a laser with megawatt power is removing the heat from the active medium while also avoiding distortion of the optical fields within the resonator. By locating the active medium at the center of the laser, and thus the waste heat, the task of thermal control is difficult. The research team plans to overcome this by using a thin disk active mirror system to locate the heat load externally.

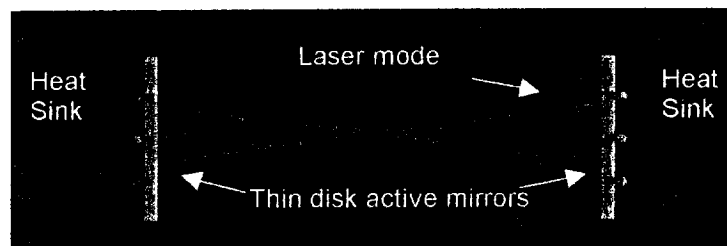


Fig. 1. A thin disk laser oscillator locates the active medium and hence the primary heat load on the laser at the exterior surface of the resonator. The bonded contact with a heat sink and short extraction path allow rapid heat removal with minimal optical distortion of the critical internal laser oscillator fields.

Using the thin disk system as shown above, powers in the tens of kilowatts are possible, but additional technologies were needed to scale to the laser to megawatt power.

2. Frequency Space Modelocking

A strategy for retaining a compact structure and increasing power is that of distributing many thin disk active mirrors over the entire surface area, filling the interior of the laser structure with optical modes. These have a multiplicity of spatial axes, but are coupled and locked to a common phase. Phase locking of a few different spatial modes has been achieved. A primary step is to simplify the number of modes that must be locked in phase to a manageable subset of the possible modes. The next step is to use a combination of active stabilization (real time sensing and active control) and nonlinear optical techniques (stabilization via nonlinear optical interactions) that will maintain the desired coherence.

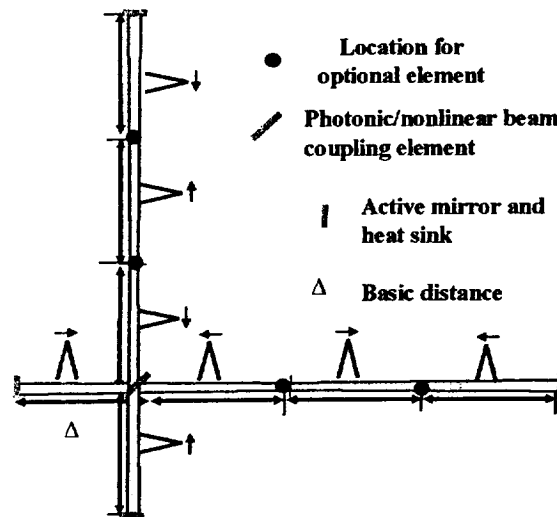


Fig. 2 Basic building block for frequency space modelocking (FSM). Multiple lowest order Gaussian T_{00q} modes having spatially resolved optical axes are coupled via a beam coupling element and locked in phase by a combination of active and nonlinear optical means.

This combination of spatial and frequency modelocking described above has been used successfully.

3. Formation of the SHEL Structure

We developed strategies for placing the active mirrors supplying more than the order of the megawatt of power over an exterior surface area. This allows the use of a phase change cooling system at the exterior surface. Then we can continue to build the system by adding more beams of the same or different wavelengths.

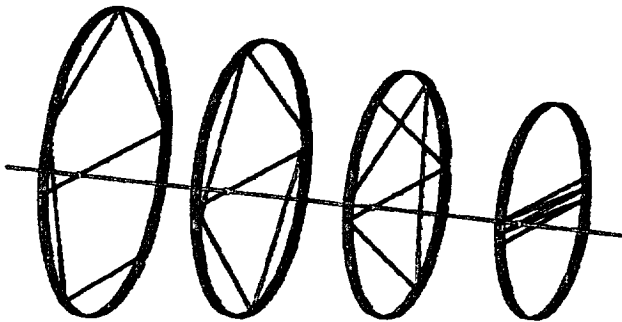


Fig. 3. The laser beams (blue) of the coupled resonators are amplified by active mirrors located on a ring centered on the axial resonator. The power produced in the active mirrors is coupled via the resonator coupler (white dots) to the axis beam.



Fig. 4. This is an expanded version of the previous diagram using four stacks of rings. The system has a modular character designed to facilitate interchange of individual rings if necessary. The multiple sets of beams having the same and different wavelengths are folded and structured so as to place the active heat producing elements (blue dots) on the exterior surface. The complete system will have ten stages of 12 rings per stage.

4. Thermal Management

The thin disk active mirror system places the heat load on the external surface which allows for faster heat removal and less optical distortion. The most researched method of cooling was phase-change cooling. The two liquids that were most heavily studied for this process were water and liquid nitrogen. One benefit liquid nitrogen has over water is that the low operating temperature of liquid nitrogen helps to raise efficiency and extend the durability of the components. Wesley Walker researched and graphed the relationship between operating temperature and efficiency.

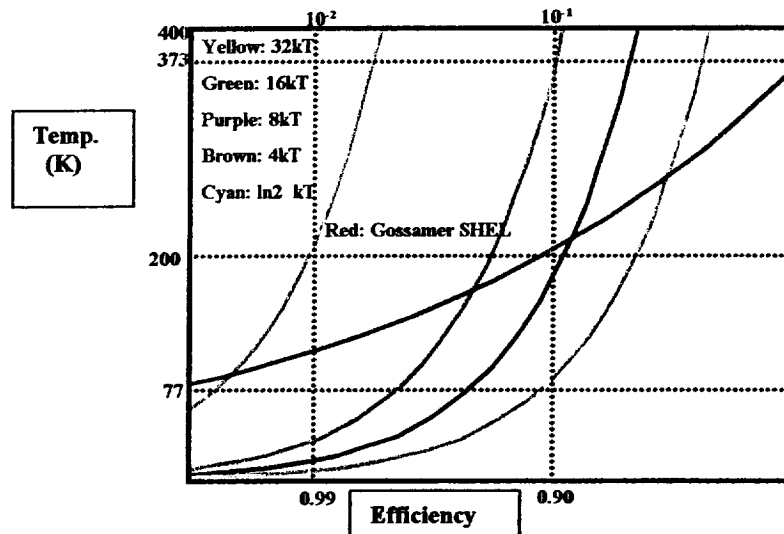


Fig. 5. This graph shows the relationship between temperature and efficiency for different wavelengths of light.

5. Solar Energy Collection

Plans for the Gossamer Laser satellite were designed during the past year. The purpose of this satellite is to collect sun light and convert it into a single coherent beam to be sent to earth and converted to electricity. The wings of this satellite could be rotated in such a way as to always be facing the sun.

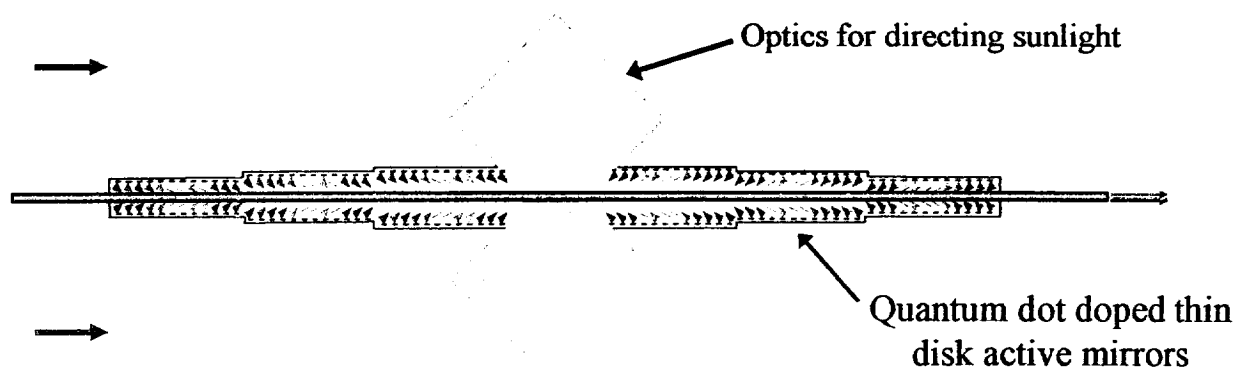


Fig. 6. This is the schematic for the solar collection satellite, the Gossamer Laser.

6. Delivery of Laser Diode Pump Light

An efficient source of pump light must be supplied to the laser in order for it to function well and scale to higher power. Most likely a system of laser diodes will be used to

pump the multiple rings of the SHEL structure. The ultimate source for the energy needed for these laser diodes will be sunlight. There are two methods for converting the sunlight into a single coherent beam. The first would use solar cells to produce electricity which would power laser diodes which would serve as pump light. The more cutting edge path that was examined is to use the sunlight directly. For this to work properly, a strategy of spectral multiplexing will be used to separate the broad spectrum of sun light into its many different wave lengths. In this manner light of a barely shorter wavelength powers the laser diode pump source of a given wave length. This light will be sent directly to the thin disk active mirrors to serve as the pump light.

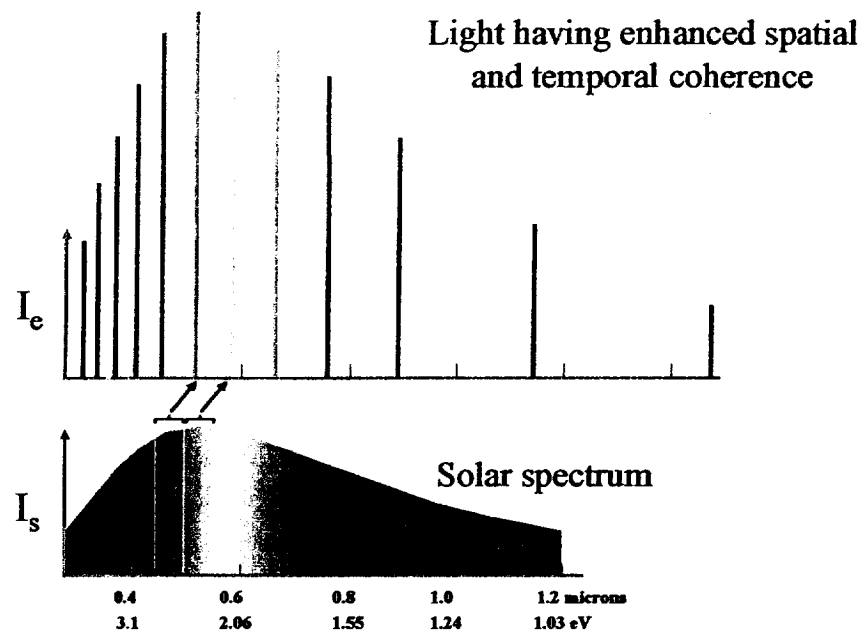


Fig. 7. The solar spectrum is broken into its various wavelengths and energy from the shorter wavelengths is used to power the slightly longer wavelength of a laser diode.

7. Conclusion

The goal of this project was to examine the viability of constructing a safe and effective power beaming system for space. The many problems of producing a single coherent beam that produces meaningful amounts of electricity were examined and possible solutions to these problems were explored. One emerging technology that could definitely make this project successful is that of quantum dot lasers. Quantum dot lasers have extremely broad gain spectrums and are highly temperature insensitive. A system of interferometric real time metrology based on feedback from laser pulses will be used to monitor the various lengths of the different resonators in order to maintain the ideal conditions needed for the frequency space modelocking to occur. These theories along with the emerging technologies should make possible the design and fabrication of a space based wireless means of transporting electricity.

Acknowledgements

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